THE SOUTHERN HIGHLANDS MAIZE IMPROVEMENT PROGRAMME: ACHIEVEMENTS AND STRATEGIES FOR FUTURE RESEARCH

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ABSTRACT

Maize (Zea mays *L.) is the most important staple food crop in Tanzania. Production has increased substantially over the last 20 years as a result of an expansion in acreage as well as the adoption of improved production technology. In the Southern Highlands, research activities carried out at Uyole Agricultural Centre (UAC) have facilitated the release of several maize cultivars and the formulation of various agronomic packages. The increase in improved seed sales and fertilizer use, as well as in the maize grain yields obtained by farmers adopting the recommended agronomic packages, all reflect the value of UAC's maize research efforts. However, lack of credit facilities, in timely and in sufficient availability of production inputs, high input costs and unreliable marketing channels are major constraints that still hamper the adoption and full utilization of the recommended maize production technology.*

The selection of higher yielding and maize streak virus (MSV) resistant hybrids and cultivars, the refinement of management packages for the range of ecological zones that occur in the Southern Highlands, and the maintenance of soil fertility are among the topics on which further research is planned in the Southern Highlands Maize Improvement Programme.

INTRODUCTION

Maize (*Zea mays* L.) is the most important staple food crop in Tanzania. Production statistics (FAO, 1990) show that maize occupied 40% of the total area under major food crops in Tanzania between the years 1987 and 1989. Being largely a subsistence crop produced by smallholders, maize is a crop that probably has the greatest potential for alleviating hunger in this country. Although maize is widely grown, the Southern Highlands, comprising the regions of Iringa, Mbeya, Rukwa and Ruvuma, provide some of the most favourable conditions for its economic production. Estimates of maize production by region between the years 1984 and 1987 show that this zone accounted for 46% of total maize production in the country (Moshi and Nnko, 1989). Despite its importance, various constraints still hamper maize production. Yields are still poor, averaging only 1.5 t ha^{-1}. Increases in maize production as a result of both an increase in the cropped area and increased production per unit area are possible, but, these will depend heavily on better exploitation of the great potential that exists within the Southern Highlands of Tanzania.

The objective of this paper is to review past maize research work and its benefit to smallholders in the Southern Highlands, to identify constraints to the adoption of improved practices, to suggest a sequence of innovations for implementation by extension workers and, finally, to suggest guidelines for future research.

RESEARCH REVIEW

Maize research at Uyole Agricultural Centre (UAC) started in the 1970/71 cropping season under the Tanzania-Nordic Agricultural Project. Before this, research at other research institutes, had already resulted in some agronomic recommendations, which contributed to increased maize production in the mid 1960s and early 1970s. A nationally co-ordinated maize research programme was begun in 1974 under the technical leadership of the International Centre for the Improvement of Maize and Wheat (CIMMYT), whose first task was to set up the National Maize Research Programme (NMRP). Following the establishment of the NMRP, the scope of research activities at UAC widened somewhat, especially in the area of village trials, research, which facilitated the verification of agronomic packages under farmers' field conditions while serving as demonstration plots at the same time.

Testing of full sib progenies and experimental cultivars from several high elevation populations and the development of a long season composite cultivar were carried out at UAC by the plant breeder from Ilonga Research Institute. The maintenance of inbred lines for hybrid seed production, most of which are still in commercial use today, was also carried out in collaboration with the Tanganyika Wattle Company (TANWAT) at Njombe, which had acquired these materials from the Maize Genetics Programme at Kitale in Kenya.

The direct involvement of CIMMYT came to an end towards the end of 1983, giving way in 1985 to the formation of the Southern Highlands Maize Improvement Programme (MIP) a sub-programme of NMRP. The Southern Highlands MIP was established specifically to handle maize research work relevant to the Southern Highlands.

Maize research activities carried out at UAC over the years have led to many useful findings, which have been used to develop packages of agronomic recommendations for the various agro-ecological zones found in the Southern Highlands. A brief summary of the most important findings is presented below.

Variety evaluation

Collaboration with the Maize Genetics Programme at Kitale in Kenya, has facilitated the identification and, eventually, the release of a number of hybrid maize cultivars suitable for production in the Southern Highlands and in other areas with similar growing conditions (Table 1). With good management, such as is found in large scale operations and progressive smallholder farmers' plots, grain yields of 6 to 7 t ha^{-1} can be achieved using the hybrid cultivars H6302 and H614. TMV-2, an open pollinated cultivar released in 1987, has a yield potential comparable to that of current hybrids and may therefore, be a good substitute. A new experimental hybrid, EH85608, has been identified and will be released after verification in on-farm trials. Continuing research efforts towards the breeding of new hybrids for the intermediate elevation zone have already shown promising results (UAC, 1991/92); several entries yielded up to 9 t ha^{-1} in the initial series of single cross-evaluation trials.

Table 1. Yield (t ha^{-1}) of high and mid-altitude maize cultivars in on-station trials

	High altitude (>1500 m asl)			Mid-altitude (1000-1500 m asl)	
	10-year mean	1990/91		5-year mean	1990/91
H6302	7.6	8.3	H632	3.9	3.7
H614	7.4	8.5	Kilima	4.6	4.2
TMV-2[1]	6.7	9.5	TMV-1	4.5	5.4
EH85608[2]	7.6	9.5	UCA	4.2	5.3
No. of sites	4	4		6	6

[1]Mean based on six years; [2]A new experimental hybrid, mean based on three years.
Source: NMRP progress reports, 1980/81 to 1990/91.

Time of planting

Planting time has been identified as one of the most crucial aspects of management for profitable maize production in the Southern Highlands. Grain yield reduction is almost directly proportional to the length of time that planting is delayed after the onset of the rains (Table 2).

In the Southern Highlands, the grain yield lost due to the late planting of recommended hybrid varieties was 62 kg ha^{-1} for day's delay after the first rains. In Kenya, Auckland (1971) reported a grain yield loss of 55 to 110 kg ha^{-1} d^{-1} for late planted maize in the Rift Valley, while losses as high as 170 kg ha^{-1} d^{-1} were recorded in the drier areas of the Central and Eastern Provinces.

A strong interaction between time of planting and other factors, such as variety and nitrogen fertilizer, has been observed (UAC, 1974/75). The yield of hybrids, because of their delayed maturity, declined faster with delayed planting than that of composite varieties. The best response to applied nitrogen fertilizer (measured in terms of kg grain kg^{-1} N) was obtained with maize that was planted on time. Under conditions of moisture stress, maize planted at an optimum plant population suffered more grain yield loss with delayed planting than that planted at sub-optimal plant populations.

Table 2. Effect of planting time on maize grain yield (t ha^{-1}) at five sites in the Southern Highlands

Planting time	Uyole (1800 m)	Mbimba (1500 m)	Suluti (900 m)	Nkundi (1800 m)	Mitalula (1100 m)	Mean
1st heavy rains[1]	6.82	2.81	5.21	3.80	3.61	4.45
4 week delay	4.24	1.67	3.99	2.35	1.28	2.71
Yield reduction (%)	38	51	23	38	65	

[1]The first heavy rains occur end of November/early December.
Source: UAC Annual Report 1974/75.

Plant population and arrangement

Plant density studies carried out in the mid 1970s using recommended varieties have established the plant arrangement options and optimum plant population for tall and short statured varieties (UAC, 1974/75). For two tall statured varieties (H6302 and UCA) planted at different densities, with fertilizer, the optimum plant population was about 45,000 plants ha^{-1}, which is the current recommendation for full season maize cultivars. However, under conditions of low fertility, the optimum plant population appeared to fall anywhere between 22,000 and 33,000 plants ha^{-1}.

Evaluation of Katumani (a short statured variety) at three plant densities (50, 75 and 100 x 10^3 plants ha^{-1}) under normal and moisture-limited environments showed that short statured varieties similar to Katumani could be planted at a density of 88,000 plants ha^{-1}, which is almost twice the density recommended for tall full season varieties.

Investigations of planting arrangement showed that spacing within the row was not important, as long as a density of 4-5 plants m^{-2} was achieved (Anon, 1979). The farmer therefore has the option of choosing among a number of different spacings during manual planting without sacrificing grain yield, as long as the recommended plant population is maintained. Instead of using a spacing of 75 x 30 cm with a single plant per hill, for example, the farmer could choose a multiple stand arrangement, such as 75 x 60 cm with two plants per hill or 75 x 90 cm with three plants per hill, in order to reduce the amount of labour required at planting time.

Weeds and weed management

Weeds constitute one of the most serious barriers to increased maize production in the Southern Highlands. In the Vertisols of the Ethiopian Highland, losses due to weeds ranged from 30 to 88% (Sidorov *et al.*, 1985) and in Zambia, from 43 to 63% of yield potential (Nkhoma, 1985). In the Southern Highlands, yield reduction in unweeded plots ranges from 50 to 100% of potential yield (UAC, 1991/92).

Studies of the effect of frequency of weeding carried out in the early to mid 1970s at several locations in the Southern Highlands, and elsewhere in the country, showed that two hand weedings, carried out when the maize was 30 and 90 cm tall increased yield by over 230% (Table 3). A third weeding was found to be uneconomical.

Table 3. Effects of different times of weeding on maize grain yield (mean of five locations)

	Yield (t ha^{-1})	Increase over control (%)
No weeding (control)	2.28	100
One weeding at 10 cm stage	4.17	183
One weeding at 30 cm stage	3.88	170
One weeding at 50 cm stage	4.09	179
Two weedings at 10 and 50 cm stage	5.32	233
Two weedings at 30 and 70 cm stage	5.41	237
Three weedings at 10, 50 and 90 cm stage	5.42	238

Source: UAC, 1974/75.

Herbicide and Pesticide Evaluation

Screening of herbicides for weed control in maize has been a continuous research activity since 1970/71. Gesaprim/Luxan (atrazine) and Primagram (atrazine + metolachlor) applied pre-emergence at a rate of 5 l have given the best control of weeds in maize. Other promising alternatives have been Laddock (bentazone + atrazine), Atrannex (atrazine) and Lasso-atrazine. An evaluation of this work has been carried out and reported by Temu (1989a). Pesticide research activities are presented in Nsemwa *et al.* (1992).

Response of maize to the application of N, P and K

Maize requires substantial quantities of mineral nutrients for its vegetative and grain development. Martin *et al.* (1976) reported that a 9.5 t ha^{-1} grain yield removed 150 kg of nitrogen and 27 kg of phosphorus per hectare from the soil. Prasad (1978) noted that a maize crop producing 5-6 t ha^{-1} of grain removed 100-150 kg nitrogen and 40-60 kg P_2O_5 ha^{-1} from the soil. There are few areas in the Southern Highlands with soils that could provide such levels of nutrients without inorganic fertilizer application or other soil fertility-enhancing measures.

Nitrogen and phosphorus are the major limiting nutrients in maize production in the Southern Highlands. A response to nitrogen has been demonstrated in all the dominant soil types of the region, while a response to phosphorus is evident only in the presence of nitrogen. Little response to added potassium has been observed in most parts of the Southern Highlands. However, this element is being monitored in some intensively cropped areas.

A recent economic analysis, using data from MIP and the Food Agriculture Organization (FAO) Fertilizer Programme and input and produce prices for the 1991/92 season, revealed that the economic optimum rate of nitrogen and phosphorus application in high rainfall areas was 100 kg ha^{-1} nitrogen and 40 kg ha^{-1} P_2O_5, (Kamasho *et al.*, 1991). The main soil types and agro-ecological zones in which the fertilizer trials were conducted, and the fertilizer recommendations for each zone, have been determined and are shown in Table 4.

Methods of fertilizer application

Trials were initiated to identify the most appropriate method of applying fertilizer to ensure maximum availability of nutrients to the plant. Among the application methods tested, placement of all the phosphorus under seed at planting and split application of nitrogen (half at planting time in rows, furrows or under the seed and the rest top-dressed when the maize was 80 cm tall) was found to be the best method under smallholder farmers' conditions (Table 5).

Table 4. Fertilizer rates for maximum economic yield (in italics), and lower rates for farmers who cannot afford/obtain the maximum rates

	P (kg ha^{-1})	N (kg ha^{-1})	Expected yield (t ha^{-1})	Fertilizer cost (TSh x 10^3 ha^{-1})	Net value (TSh x 10^3 ha^{-1})	Value: cost ratio
Rukwa: Ufipa Plateau	0	0	0.8	0.0	22	-
(cambic Arenosols)	10	0- 60	1.7-3.7	2.6-11.4	42-85	8-6
	20	*60-100*	*4.1-4.7*	*14.0-19.9*	*93-102*	*5-4*
Rukwa: Ufipa Plateau	0	0	0.6	0.0	15	-
(orthic Ferralsols)	10	0	2.1	2.6	51	14
	20	*0-120*	*2.9-5.4*	*5.2-22.8*	*71-118*	*11-5*
Mbeya District	0	0-100	2.2-4.6	0.0-14.6	62-121	7-4
(Phaeozems)	10	100	4.7	17.2	123	4
	20	*100*	*4.7*	*19.9*	*125*	*3*
Mbeya District	0	0-40	1.8-3.1	0.0-5.8	47-74	5
(Ferralsols)	10	40-80	3.6-4.4	8.5-14.3	84-101	4
	20	*80-120*	*4.7-5.2*	*17.0-22.8*	*106-113*	*4-3*
Mbozi District	0	0- 40	1.0-2.1	0.0-5.8	27-49	4
(Ferralsols)	10	40-80	2.6-3.3	8.5-14.3	58-71	3
	20	*80-120*	*3.6-3.9*	*17.0-22.8*	*75-79*	*3-2*
Njombe Plateau	0	0- 20	1.1-2.2	0.0-2.9	29-53	8
(humic Ferralsols)	10	20-60	3.0-4.5	5.6-11.4	74-106	8-7
	20	*60-100*	*4.9-5.5*	*14.1-19.9*	*114-124*	*6-5*
Mufindi Plateau	0	0-40	1.2-2.8	0.0-5.8	31-66	7-6
(rhodic Ferralsols)	10	40-80	3.5-4.3	8.5-14.3	81-98	6-5
	20	*80-100*	*4.7-4.8*	*17.0-19.9*	*104-105*	*4*
Mufindi Plateau	0	0-40	0.8-2.5	0.0-5.8	31-66	7-6
(xanthic Ferralsols)	10	40-80	3.1-4.0	8.5-14.3	72-90	6-5
	20	*80-100*	*4.2-4.4*	*17.0-19.9*	*93-94*	*4*
Iringa Plain	0	0-40	1.1-2.3	0.0-5.8	30-60	5-4
(eutric Fluvisols)	*10*	*40-80*	*2.7-3.3*	*8.5-14.3*	*43-61*	*4-3*

Table 5. Effect of different methods of nitrogen application on maize grain yield (t ha^{-1}, mean of two nitrogen rates; all phosphorus applied at planting)

	Uyole	Suluti	Mean
Full dose at planting in rows	5.5	3.7	4.6
Full dose at planting in furrows	5.0	3.6	4.3
Full dose at planting 5 cm under seed	5.6	3.6	4.6
Half in rows + rest top-dressed	5.9	4.3	5.1
Half in furrows + rest top-dressed	5.8	4.4	5.1
Half under seed + rest top-dressed	5.7	4.1	5.0

Source: UAC, 1975/76.

Further studies carried out on the influence of three difference sources of nitrogen (sulphate of ammonia, calcium ammonium nitrate and Urea) on yield found no significant differences among them (Temu, 1989b). However, placement of a full dose of urea under the seed (which is not recommended) caused serious seedling injury, leading to a poor stand and consequently to lower yields.

Effect of nitrogen fertilizer on soil pH

The concern raised by some farmers and extension agents in the early 1980s about possible soil acidification after repeated application of nitrogen in the form of sulphate of ammonia prompted of a long term trial of its effect in 1981. After five years of the study at several locations differing in soil type and rainfall intensity, a significant drop in soil pH was found at Ismani, Mbimba, Ndengo and Suluti, but not at Mitalula. However, only slight changes in pH were observed at low rates of sulphate of ammonia application. Soil pH in plots receiving nitrogen in the form of calcium ammonium nitrate remained relatively unchanged at all sites (Table 6). No significant differences in maize grain yield were observed among the different forms and rates of nitrogen application after five years of experimentation. The optimum soil pH for good maize growth is 5.0 to 7.0. Given the relatively low rates of nitrogen which are being applied by farmers, it would appear that problems of soil acidity resulting from the use of sulphate of ammonia as a source of nitrogen should not concern smallholder farmers in the Southern Highlands, unless they are operating on soils with pH values below five.

Table 6. Soil pH after fifth year of nitrogen fertilizer application in the form of sulphate of ammonia (SA) or calcium ammonium nitrate (CAN)

	SA (kg ha^{-1})					CAN (150 kg N ha^{-1})		
	0	50	100	150	200	Yr 1	Yr 5	% change
Uyole	6.50	6.60	6.32	6.10	5.10	6.50	6.50	0.0
Mbimba	5.35	5.45	5.25	5.20	5.00	5.50	5.30	0.9
Ismani	6.62	6.15	5.20	5.40	4.50	6.60	5.90	10.9
Mitalula	5.90	5.95	5.75	5.90	5.80	5.90	5.90	0.0
Suluti	6.01	5.78	5.32	5.10	5.03	6.20	5.70	5.2
Ndengo	5.40	5.30	4.80	4.70	4.60	5.60	5.40	3.5

Source: Temu, 1989a.

Use of yard manure to improve soil fertility

The ever rising prices of mineral fertilizers, coupled with irregular supplies and farmers' inability to purchase fertilizer in sufficient quantities, are some of the problems which justify a continuous search for alternative methods of improving soil fertility for crop production. Farmyard manure can provide small amounts of nitrogen and phosphorus and has other advantages, such as the addition of organic matter to the soil, which in turn improves soil structure, water holding capacity and soil tilth.

Trials to evaluate the response of maize to farmyard manure were initiated in 1976/77. In the mid 1980s, supplementation of farmyard manure with mineral fertilizers, and the effects of residual fertilizer on subsequent crops, were studied. Maize yields increased steadily as the amount of farmyard manure was increased from 5 to 40 t ha^{-1} (Table 7). However, transportation of the material from the source to the field appears to be a big constraint, especially where use of ox-carts is uncommon. When farmyard manure was supplemented with mineral fertilizer at low rates, its potential was clearly demonstrated. Farmyard manure at a rate of 20 t ha^{-1} plus 40 kg N and 15 kg P ha^{-1} resulted in a grain yield of 7.01 t ha^{-1}, compared with 4.03 t ha^{-1} when the same rates of nitrogen and phosphorus were used without farmyard manure and 5.12 kg ha^{-1} when farmyard manure at 20 t ha^{-1} was used alone (Table 8).

The residual effects of farmyard manure on subsequent crops were unremarkable. In the third year, the maize yield from plots that had received 20 t ha^{-1} of farmyard manure during the first year dropped by 73% at Uyole and by 23% at Mbimba. Re-application of farmyard manure in the fourth year at the same rate dramatically increased yields, to 7 t ha^{-1} (UAC, 1983/84), suggesting that farmers need to make fresh applications every three years if the initial rate is of the order of 20 t ha^{-1}.

Table 7. Response of maize to the application of farmyard manure (FYM)

Rate of FYM (t ha^{-1})	Maize grain yield (t ha^{-1})	Increase in yield over control (%)
0	2.21	100
5	2.47	117
10	2.69	121
20	3.74	169
40	4.94	224

Source: UAC, 1976/77.

Table 8. Response of maize to farmyard manure (FYM) supplemented by mineral fertilizer (mean of two locations)

	Maize grain yield	% Increase
No FYM, no mineral fertilizer (control)	3.04	100
FYM at 5 t ha^{-1}	4.49	148
FYM at 20 t ha^{-1}, yr 1 only	5.12	168
FYM at 20 t ha^{-1} in yr 1 + 40 kg N ha^{-1} a^{-1}	6.82	224
FYM at 20 t ha^{-1} in yr 1 + 40 kg P ha^{-1} a^{-1}	7.01	231
40 kg N + 15 kg P ha^{-1} a^{-1}	4.03	133
80 kg N + 30 kg P ha^{-1} a^{-1}	6.28	207

Source: UAC, 1980/81.

Use of green manures

Not much is known about the potential of green manure as a source of nitrogen or soil fertility maintenance. Although leguminous crops such as common beans (*phaseolus vulgaris*), would be the most appropriate form of green manure, it is almost impossible to convince farmers to grow the crop and plough it under just for the sake of increasing soil fertility.

Crotalaria (*Crotalaria zanziberica* or *C. ochroleuca*), locally known as marejea is a potential alternative green manure. Trials to examine the use of crotalaria as a rotation crop with maize commenced in 1980/81. The crotalaria was subjected to three types of management: ploughed under as a green manure crop at 50% flowering and left to decompose; cut and removed at the same stage (simulating animal feeding); and left on the field until the seed was harvested. Superimposed on these treatments were nitrogen rates from 0 to 160 kg ha^{-1}. Results showed a clear benefit in the yield of the following maize crop from the use of the legume in particular when ploughed under (Table 9). Overall, crotalaria produced an effect corresponding to 80 kg N ha^{-1} when removed and up to 120 kg N ha^{-1} when ploughed under.

Trials conducted later to study the possibility of intercropping the legume with maize did not give promising results (UAC 1985/86, 1986/87). Without supplemental nitrogen maize yields were as low as 2 t ha^{-1}.

Further findings on the potential of crotalaria in maize production were as follows when crotalaria was seeded with maize at planting, under cool conditions (above 1500 m above sea level, it grew slowly and was overtaken by weeds. Maize requires nitrogen from the early stages of crop growth, but at this stage nodulation and nitrogen fixation in crotalaria is negligible if it is planted at the same time as the maize. When crotalaria was seeded between all the maize rows the maize harvesting was severely hampered. In warmer, rainy areas, such as Ismani or Mbimba, crotalaria established fast, and the maize was completely smothered by it.

Despite the beneficial effects of crotalaria farmers may still be reluctant to lose a season in order to plant it. It is suggested that the farmer should be advised to sow only a small part of the farm with crotalaria in any one season and then rotate crotalaria around the farm in following seasons. Alternatively, crotalaria could be seeded at the beginning of the season, say at the end of November, then ploughed under or fed to animals as forage in February or March, so that the farmer could then plant a mid-season crop, such as wheat, without the use of fertilizer.

Table 9. Effect of *Crotalaria zanziberica,* and different rates of nitrogen fertilizer on the grain yield (t ha^{-1}) of a following maize crop (at Uyole)

	Nitrogen rate (kg ha^{-1})				
	0	**40**	**80**	**120**	**160**
Maize alone, no rotation	1.40	3.26	4.00	5.16	6.31
Crotolaria removed, then maize	5.32	6.11	7.58	8.20	8.82
Crotalaria ploughed under, then maize	6.80	6.35	8.29	8.28	9.04

LSD (P<0.01) crotalaria, 0.08 t ha^{-1}; fertilizer rates, 0.21 t ha^{-1}; CV (%) crotalaria, 28; fertilizer rate, 12.
Source: UAC, 1986.

Crop rotation

Legumes are good crops to include in crop rotation, since they fix nitrogen as well as adding organic matter. Some long term trials have been conducted at UAC and at other sites, to evaluate the role of crop rotations on maize yield (Table 10). The treatments in which maize was grown after fallow received 120 kg N ha^{-1}, while maize preceded by beans, lupins or crotalaria received 75 kg N ha^{-1}. Phosphorus at 40 kg P_2O_5 ha^{-1} was applied to all treatments. In general, the maize yield was higher when the maize was grown in rotation with a legume than when it was not even when fertilizer was used.

Table 10. Maize grain yield (t ha^{-1}) in the fifth year when grown continuously and when grown in rotation with different legumes (at Mbozi Maize Farm)

	Maize yield in 5th year
Maize grown continously for five years	5.59
Maize alternated with one year of crotalaria left to seed	7.63
Maize alternated every two years with crotalaria ploughed under	8.16
Maize alternated every year with crotalaria ploughed under	8.73
Maize alternated with beans annually	6.00
Maize alternated every two years with beans	5.32
Maize alternated every two years with fallow	5.48
Maize alternated every two years with lupins ploughed under	6.90

LSD (P<0.05), 2.07 t ha^{-1}; CV (%), 20.6.
Source: UAC, 1987/88.

ACHIEVEMENTS AND CONSTRAINTS

There are a number of indicators that suggest that efforts to disseminate maize production technology by means of village trials and field day demonstrations, refresher courses for extension agents, as well as leaflets and handbooks, and by the of extension agents themselves, have been successful in the Southern Highlands.

The adoption of some components of maize production recommendations, such as those on plant population, plant arrangement, timely planting and weed control, is clearly visible on many small farms across the Southern Highlands. Sales of improved seed have increased from a meagre 25 t of hybrid seed in 1970 to over 6000 t on average between 1987 and 1991 (Orondo, 1988), most of which was sold to smallholder farmers in the Southern Highlands. The Sasakawa Global 2000 Agricultural Project, whose objective has been to assist smallscale farmers adopt productivity-enhancing technology through the provision of production inputs on credit, has shown clearly the viability of agronomic recommendation packages developed at UAC. This project has also demonstrated that the alleviation of even a few of the constraints that face smallholders can go a long way towards helping realize the potential of the Southern Highlands for maize production. Over the 1989/90 season, average maize yields from 100 one acre (about 0.4 ha) plots (referred to as management training plots or MTPs) in 10 villages in Rukwa region ranged from 3.5 to 5.6 t ha^{-1}, compared with to 1.5 to 1.9 t ha^{-1} from farmers' traditional plots. Grain yield from 100 MTPs involving 8 villages in Mbeya Region ranged from 2.9 to 6.2 t ha^{-1}, compared with 1.7 to 2.8 t ha^{-1} from farmers' traditional plots. In Iringa, grain yields in 30 villages from 320 MTPs ranged from 2.7 to 7.3 t ha^{-1} compared with 1.8 to 3.0 t ha^{-1} from farmers' traditional plots (Russell and Dowswell, 1992). Maize grain yields from MTPs during the 1990/91 season are shown in Table 11.

The grain yields levels obtained from MTPs so far are similar to those obtained by large scale producers, such as in Mbozi Maize Farms in Mbeya and Tanganyika Wattle Company (TANWAT) in Njombe, where yields range from 5 to 6 t ha^{-1}. Some farmers in Iringa have obtained up to 9.5 t ha^{-1} (Natai, personal communication), a yield similar to that obtained in well managed on station experimental plots.

Although the adoption of the current maize production recommendations has proved beneficial, there are several major constraints to the full adoption of maize production technology by farmers in the Southern Highlands, as are listed below:

Table 11. Maize yields (t ha^{-1}) from a random set of management training plots grown in various districts during the 1990/91 season.

District	Village	Yield range	No. of farmers	Mean yield
Iringa	Kitowo	3.8 - 6.5	200	5.2
	Magulilwa	3.5 - 6.0	129	5.0
	Nguruhe	4.0 - 6.0	70	5.1
Mufindi	Nundwe	5.0 - 7.3	10	NA
	Changarawe	4.3 - 6.3	10	NA
	Itulavanu	4.3 - 7.0	10	NA
Sumbawanga	Ikozi	2.8 - 8.0	81	6.0
	Lula	3.0 - 7.5	82	4.9
	Matai	3.3 - 6.5	46	5.0
Nkasi	Kalundi	3.0 - 6.8	10	5.7
	Nkana	3.0 - 6.3	10	4.2
	Katani	2.5 - 5.8	10	4.5

NA, not available.

Source: Sasakawa Global 2000 District Co-ordinators' offices.

1. A poor resource base is made worse by the lack of efficient credit facilities. Although many farmers in the Southern Highlands are aware of what is needed to produce a good maize crop, most of them are too poor to afford the inputs required. The dramatic increased in yields achieved by villagers who have taken advantage of the credit facilities provided by the Sasakawa Global 2000 project clearly demonstrate the value of credit facilities as a means of assisting smallholder farmers to increase total maize production in the Southern Highlands.

2. In many cases, the recommended production inputs are not available when and as required by farmers.

3. Unreliable marketing channels and inadequate incentives for producers discourage some potential farmers from looking at maize production as a reliable source of income.

4. Many inputs, especially fertilizers and herbicides, are too expensive for the ordinary farmer to use, even though inadequate soil fertility and weeds constitute serious production problems in the Southern Highlands.

SEQUENCE OF INNOVATIONS FOR MAIZE PRODUCTION

Although many farmers are aware of the recommended agronomic packages for various crops, they do not generally adopt complete packages. Instead, they tend to adopt one or two components of a package at a time, because of such things as capital and labour constraints.

To develop an appropriate sequence of innovations for introduction to farmers requires an understanding of the farming systems of an area. This is important so that one can identify a component or combination of components that might increase yield and income, identify innovations acceptable to a particular group of farmers, and understand what management factors could or should be adopted first and which should not be introduced until other practices have been accepted by farmers.

The sequence of innovations presented below and summarized in Table 12 begins with a hypothetical farmer working at a very low management level, who then moves step by step in the direction of higher management levels until optimum production is reached.

1. *Weeding.* Reducing the competition from weeds in the maize field is always beneficial, regardless of the maize variety used, soil fertility level, and how other production practices are carried out. Assuming that 10 person days are spent per hectare on weeding, at TSh 577 per person day (300-400 TSh = US$1 approximately, 1992), an additional 144 kg of maize is required as a minimum to justify the weeding operation (at the 1992 open market price for maize TSh 40 kg^{-1}). However, it is known that one timely weeding may increase yield by over 100%. If the yield increases from 300 to 700 kg ha^{-1}, there will be a net benefit of TSh 9,653.

2. *Timely planting.* In most areas early planting is a necessary precondition for high yields and therefore gives a good return on investment. This innovation may be adopted at almost no cost. It is estimated that timely planting together with timely weeding should raise yields from 700 to 1200 kg ha^{-1}.

3. *Improved fertility.* Given timely planting and weeding the use of, mineral fertilizers would be the next logical step in the sequence. Use of a moderate amount of nitrogen (40-50 kg N ha^{-1}) plus 20 kg P ha^{-1} as a basal application at planting, would be appropriate at this stage. Application of phosphorus is needed, particularly on phosphorus-deficient soils, in order to get a good response to applied nitrogen. The quantity of fertilizer applied may later be adjusted upwards or downwards according to the farmer's financial circumstances and yield expectations. Assuming, for example,

that a farmer applied 50 kg N ha^{-1} and 20 kg P ha^{-1} all at planting time, the cost of applying the fertilizer would be minimized because planting and fertilizer application would be done on the same day. An extra three person days is required for fertilizer mixing and placement before planting. Three person days will be required for the additional harvesting and shelling of the expected extra 900 kg of maize. The yield is expected to increase from 1200 to 2100 kg ha^{-1}, resulting in a net benefit of TSh 24,223 (assuming the nitrogen is supplied as urea at TSh 1800 per 50 kg bag, and the phosphorus is supplied as triple superphosphate at TSh 2200, and including TSh 100 for transport, if the farmer is able to acquire fertilizer within 50 km of the farm).

4. *Plant Population.* Having adopted these innovations, the farmer could further increase adjusting the grain yield by plant population, say from 22,000 to about 450,000 plants per hectare. Doubling the number of holes to be planted will require an extra two person days and a roll of sisal twine (at TSh 300) for marking the rows. An additional 600 kg ha^{-1} can be expected, with yields increasing from 2100 to 2700 kg ha^{-1} which is equivalent to a net benefit of TSh 21,392.

5. *Improved seed.* Improved varieties have been shown to yield 200 to 300% higher than farmers' local unimproved varieties. At this juncture, the farmer should benefit from using improved and adapted hybrids or open pollinated varieties. Twenty kilograms of seed per hectare will be required at TSh 200 kg^{-1}. The difference between the cost of hybrids and open pollinated varieties, and of seed transport, are assumed to be negligible. Extra labour will be required only at the time of harvesting and shelling to cope with the extra yield. Use of improved seed should bring in an extra 1100 kg of maize, resulting in an estimated yield of 3800 kg ha^{-1}. A net benefit of TSh 36,000 can be expected.

6. *Further improvements in fertility level and a second weeding.* Having adopted to the preceding measures, the farmer may be motivated enough to attempt additional management steps to at increase yields still further. The major constraint at this point is likely to be soil fertility. Since improved varieties respond well to improved soil fertility, an additional 50 kg N ha^{-1} top-dressed after the second weeding should increase yield by of 2200 kg ha^{-1} to 6000 kg ha^{-1}, resulting in an extra benefit of TSh 6600 ha^{-1}.

7. *Pest Control.* In the Southern Highlands, grain yield losses due to stalk borer damage may be as high as 20%. Severe attacks and the resulting grain yield loss are easily noticeable and therefore the farmer may not hesitate to seek means of protecting the crop. An appropriate insecticide, such as cypermethrin (Cymbush) dust, applied at the correct time and at the a recommended rate should give excellent control. This could result in a 20% increase in yield, from 6000 to 7200 kg ha^{-1}, bringing in a net benefit of TSh 34884.

Table 12. Summary of a suggested sequence for the introduction of innovations to farmers to improve maize production.

Management Practice	Characteristics	Estimated Yield (kg ha^{-1})
Zero management	Extremely low management level (an unusual situation)	300
One timely weeding	Weeding, 2-3 weeks after planting	700
Timely planting	Planting at optimum time (2 weeks after onset of rains)	1200
Fertility improvement	20 kg P + 40-50 kg N ha^{-1} (basal application)	2100[1]
Optimum plant population	Spacing at 75 x 60 cm, 2 plants per hill	2700
Improved seed	Hybrid composite	3800
Further fertility improvement	50 kg N ha^{-1} (top-dressed) plus second weeding	6000
Pest control	Control of stalk borers	7200

[1]This assumes a low fertility soil. On soils of high fertility, yields will be higher.

PRIORITIES AND STRATEGIES FOR FUTURE RESEARCH

To continue supporting the farming community of the Southern Highlands, the Maize Improvement Programme will carry out further breeding and agronomic research in future as shown below.

Breeding

- Continue with on-going testing of single and three way crosses, to identify new hybrids for the intermediate elevation maize-producing areas of the country.

- Carry out population improvement taking into consideration heterotic grouping, to support the breeding of new hybrids and synthetic cultivars as a long term objective.

- Incorporate disease resistance into both new and current commercial varieties, with particular emphasis on maize streak virus (MSV) which is now a serious problem in the intermediate elevation maize-producing areas of the Southern Highlands.

- Continue providing improved seed as required to seed producing agencies to support the commercial production of hybrids and open pollinated maize cultivars.

Agronomy

- Refine management packages to improve their suitability for the various ecological zones of the Southern Highlands and farmers' circumstances, through on-farm research in collaboration with the farming systems research team at UAC.

- Conduct studies on low input agriculture, focusing on the use of green and farmyard manures, compost, crop rotations and intercropping.

- Evaluate chemical and integrated weed control methods for weed management.

- Test and establish recommendations specifically for maize production under irrigation in the Usangu Plain. Current agronomic recommendations are based on rain-fed crops and may or may not apply to irrigated systems.

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